A comparative study of Bulk Viscosity of strongly interacting systems

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Introduction

The concept of 'perfect fluidity' for the matter produced in high energy heavy ion collision experiments eventually went wrong with the advent of Au+Au and Cu+Cu collisions at RHIC. This gave rise to the question of presence of viscous effects in the system.

Bulk viscosity in this context appears due to local isotropic deviations from equilibrium and theoretically it is manifested by an addition of diagonal term $\pi\delta^{ij}$ to stress tensor in the local rest frame. There have been quite a few attempts to predict the behavioral nature of bulk viscosity as discussed in [1]. In this work, our motivation is to consider two different mechanisms namely those of Kubo formalism based on QCD sum rule approach and Relaxation Time Approximation (RTA) based on quasiparticle consideration, under the framework of 2+1 flavor Polyakov-Nambu-Jona-Lasinio model with upto eight quark type of interactions and draw a correspondence between them by studying the effects of bulk viscosity.

Formalism

Kubo Formalism connects the coefficients of viscosity to the correlation functions of energy-momentum tensor. Making use of low energy theorem for QCD and Kramers-Kronig relation with some standard thermodynamical relations, the bulk viscosity coefficient ζ takes the form [1],

$$\zeta = \frac{1}{9\omega_0}\Bigg[Ts\left(\frac{1}{c_s^2}-3\right)+\left(\mu\frac{\partial}{\partial\mu}-4\right)T^5\frac{\partial(\frac{P}{T^4})}{\partial T} + \left(T\frac{\partial}{\partial T}+\mu\frac{\partial}{\partial\mu}-2\right)\langle m\bar{q}q\rangle_T + 6\left(f_\pi^2M_\pi^2+f_K^2M_K^2\right)+16|\epsilon_v|\Bigg], \quad (1)$$

where an ansatz has been made for the spectral density, in the low frequency region as discussed in [1] and references therein.

Relaxation Time Approximation is another way to derive an equivalent expression for ζ in kinetic theory approach. Here in RTA method, the relaxation time basically measures the deviation of the system from its equilibrium state. The final expression reads as,

$$\zeta = \frac{12}{T}\int\frac{d^3k}{(2\pi)^3}\frac{f_\Phi\left[1-f_\Phi\right]}{(E_k)^2\,\Gamma}\left[\left(\frac{1}{3}-c_s^2\right)k^2-c_s^2\frac{d}{d\beta^2}\left(\beta^2m^2\right)\right]^2. \quad (2)$$

The detailed derivation of this can however be found in [2]. The effect of Polyakov loop is absorbed entirely in the modified distribution function f_Φ. E_k is the single quasiparticle energy and $\Gamma=\frac{1}{\tau}$ its thermal width determining its relaxation time τ in the medium.

Results and discussions

In upper panel of Fig. (1), we have plotted ζ for two different values of ω_0, which inversely control the numerical strength of ζ. They exhibit peak like structures near the crossover

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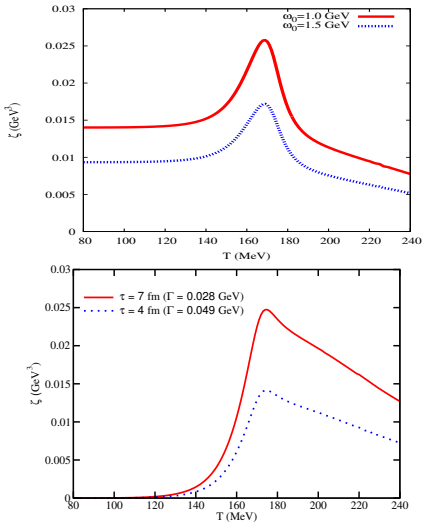

FIG. 1: ζ as a function of temperature at vanishing chemical potential obtained from Eqs. (1) and (2) respectively.

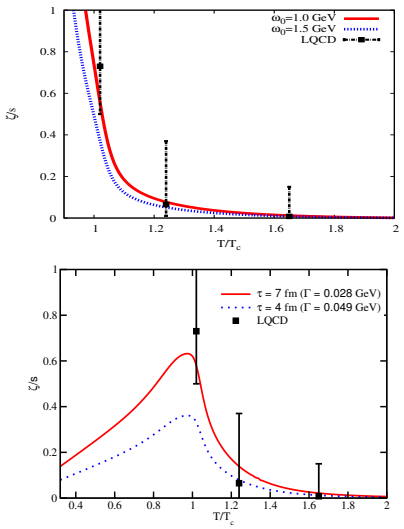

FIG. 2: $\frac{\zeta}{s}$ as a function of temperature at vanishing chemical potential in the sum rule (upper panel) and quasi-particle (lower panel) approaches.

transition temperature, T_c ∼169MeV. The deviations of each term present in Eq. (1) from conformality are collectively responsible for such nature of ζ, as discussed in detail in [1]. In the lower panel, we have plotted the outcome of ζ from Eq. (2). Two certain values of Γ or τ have been chosen so as to approximately reproduce ζ in the same order of magnitude compared to the previous cases of ω_0=1 and 1.5GeV. An equivalence between two sets of parameters thus reads as,

$$\tau = 4 \text{ fm or, } \Gamma = 0.049 \text{ GeV} \equiv \omega_0 = 1.5 \text{ GeV}$$
$$\tau = 7 \text{ fm or, } \Gamma = 0.028 \text{ GeV} \equiv \omega_0 = 1 \text{ GeV}.$$

Here we have focused on the quantitative matching near the transition region where peaks appear. A possible reason for the differences in the results away from T_c in the two panels of Fig. (1) could be that in Eq. (2), the conformal symmetry breaking term appears to be folded by the PNJL distribution function, whereas Eq. (1) does not show any such issue.

Fig. (2) shows specific bulk viscosity, $\frac{\zeta}{s}$ from the two approaches with the same set of parameters. Discrepancies occur for $T < T_c$, as ζ in the sum rule approach is quite larger compared to that in quasiparticle approach. In the high temperature domain, both of them show satifactory agreement with the existing Lattice-QCD results [3] and tend towards zero.

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